

$$\frac{d\theta}{dt} = \frac{\partial \theta}{\partial t} + \frac{\partial \theta}{\partial x} \frac{dx}{dt} + \frac{\partial \theta}{\partial y} \frac{dy}{dt} + \frac{\partial \theta}{\partial z} \frac{dz}{dt}$$

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complementary connection means is co-operable with the first connection means of any of the distribution circuits during which time the high voltage is turned off. The storage tank can be retained on the arm or can be exchanged for a filled tank at the first connection means.

5 The U.S. Patent No. 5,772,125 shows a machine for spraying a coating material which machine includes a sprayer, an on-board supply tank having first connection means, a coating material changing assembly having second connection means, and a mobile subassembly carrying the sprayer, the supply tank and the changing assembly. At least one of the connection means is movable between a coupling position and an
10 isolated position relative to the other connection means.

The art continues to seek improvements in reducing both the cycle time and in the amount of wasted paint during a color change operation. Reducing the cycle time increases both painting capacity and production capacity because more objects can be painted in a given amount of time. Reducing the amount of paint used by the robotic paint applicator represents an obvious cost savings.

SUMMARY OF THE INVENTION

The present invention concerns a bell applicator for reducing a cycle time for refilling or changing a paint color. The bell applicator according to the present invention 20 accomplishes this by combining some of the necessary steps in the cycle time. First, the paint applicator internals are cleaned while the applicator is en route to filling station. After the applicator arrives at the filling station, the external shroud is cleaned at the same time that the canister is being refilled with a new paint color.

The bell applicator according to the present invention also reduces the amount of 25 wasted/excess paint that is common in the prior art applicators. The bell applicator according to the present invention is fed by an internal canister and is carried on the robot wrist. The applicator docks with a paint filling station that can supply multiple colors and is mounted either on the robot carriage or turret and thus moves with the robot, or at a fixed location in the booth within the reach of the robot.

30 The filling station has a plurality of paint injectors, one for each color, that can be selectively moved to a docking position to engage a paint receptacle on the applicator. The bell applicator external shroud can be washed while the canister is being filled. This color

change approach offers cycle time and paint savings. The design alternative of using the robot to position the applicator to engage with a fixed injector is less favorable due to limitations of the robot reach and dexterity while rotating a typical 60-degree bell applicator in a filling station.

- 5 The bell applicator according to the present invention also incorporates provisions onboard the robot to clean the internal paint supply components including the canister, the cup and the distributor. An automatic valve mounted on the robot is designed to alternately control the supply of cleaning fluids to the uncharged bell or electrically isolate supply and dump lines from a charged bell. The bell can be cleaned en-route to the filling station thus
- 10 reducing cycle time.

DESCRIPTION OF THE DRAWINGS

- The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred
- 15 embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a perspective view of a bell applicator painting robot having a voltage block and color change apparatus in accordance with the present invention;

Fig. 2 is a perspective view of a first embodiment filling station for use with the apparatus shown in Fig. 1;

- 20 Fig. 3 is a perspective view of a second embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 4 is perspective view of a third embodiment filling station for use with the apparatus shown in Fig. 1;

- Fig. 5 is an enlarged schematic cross-sectional view of the manifold and paint
- 25 injector shown in Fig. 1;

Fig. 6 is a schematic cross-sectional view of the robot arm with bell applicator and the paint injector shown in Fig. 1;

Fig. 7 is an enlarged cross-sectional view of the paint injector shown in Fig. 5;

Fig. 8 is a cross-sectional view of the fluid control valve shown in Fig. 6;

- 30 Fig. 9 is a table of the operating sequence of the voltage block and color change apparatus according to the present invention;

Fig. 10 is a perspective view similar to Fig. 1 showing an alternate mounting location for the voltage block and color change apparatus in accordance with the present invention;

Fig. 11 is perspective view of a fourth embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 12 is a cross-sectional view of a prior art bell applicator and Fig. 12A is an enlarged portion of Fig. 12;

Fig. 13 is a cross-sectional view of the bell applicator shown in Fig. 1 and Fig. 13A is an enlarged portion of Fig. 13;

Fig. 14 is a cross-sectional view of a robot arm and bell applicator according to the present invention;

Fig. 15 is an enlarged cross-sectional view of the canister servomotor and enclosure shown in Fig. 14;

Fig. 16 is a schematic of the fluid circuits of the bell applicator shown in Fig. 14 and an associated docking station;

Fig. 17 is a table of the operating sequence of the fluid circuits shown in Fig. 16 during a paint color change;

Fig. 18 is a table of the operating sequence of the fluid circuits shown in Fig. 16 during a refill of the same color paint;

Fig. 19 is a perspective view of the bell applicator shown in Fig. 14 with a fifth embodiment filling station; and

Fig. 20 is a cross-sectional view of one of the injectors shown in Fig. 19 with the bell applicator in a docking position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 shows a painting robot **R** having a bell applicator **1** mounted on a robot wrist **2** attached at an end of an arm **A** of the robot. The robot **R** can move the arm **A** to place the applicator **1** inside a filling or docking station **3** that is either fixed in a paint booth **4** or mounted on a carriage **5** of the robot. Multiple paint supply lines **6** feed paint of various colors from storage tanks (not shown) to the filling station **3** and the lines can be selectively connected to fill a paint canister in the arm **A**. The filling station **3** includes a shroud washer **7** that can function as the canister is filled. A fluid control

valve 8 mounted on the robot arm A allows the internal paint passages of the bell applicator 1 to be cleaned as the robot R moves from a painting position toward the filling station 3 to align a shroud of the bell applicator 1 with the shroud washer 7. The filling station 3 includes a plurality of paint injectors 11 each connected to an associated one of the paint supply lines 6 for selectively coupling with a bell manifold 30 on the bell applicator 1 for filling the paint canister as described below.

A rotary version of the filling station 3 is shown in more detail in Fig. 2. A first embodiment filling station 3a fills the canister of the bell applicator 1 with paint of a desired color and washes the shroud 9. The multiple paint supply lines 6 deliver several colors of paint to the filling station 3a. Each of the supply lines 6 is connected to an associated one of a plurality of paint injectors 11 arranged in a circular pattern with their engagement axes 12 aligned parallel to each other. The injectors 11 extend upwardly from an upper surface of an annular manifold turntable 13. The injectors 11 are centered about a vertical axis of rotation of the turntable 13 that is driven in rotation by a rotary indexing means 14. The shroud washer 7 is centered under the turntable 13 such that the robot R can position the shroud 9 in the washer 7 while simultaneously engaging a paint receptacle of the bell manifold 30 (Fig. 1) of the bell applicator 1 with a selected one of the paint injectors 11 that has been rotated to a docking position. The paint supply lines 6 are routed into a single bundle that twists about a rotational axis 15 of the turntable 13.

An alternate offset rotary arrangement of the injectors 11 is shown in Fig. 3. A second embodiment filling station 3b has the rotational axis 15 of the turntable 13 offset from an engagement axis 10 of the bell applicator 1 with the shroud washer 7. This arrangement provides a clear routing path for a shroud washer fluid supply line 56 and a drain line 57 that does not interfere with the paint supply lines 6 as they twist. The paint supply lines 6 can be routed more compactly since the enclosure of the washer 7 does not occupy the same space.

Another or third embodiment filling station 3c is shown in Fig. 4. A linear arrangement of the injectors 11 is possible for movement along a straight path as indicated by a double-headed arrow 16. The injectors 11 extend upwardly from an upper surface of a linear manifold 28. A corresponding linear indexing means 17 drives the manifold 28 to position the selected injector 11 at a docking location. This arrangement

retains the single shroud washer 7 at the docking location and may provide for a more compact and reliable routing of the paint supply lines 6 within a linear cable track 18.

As shown in Figs. 5 and 6, the injectors 11 are designed to mate with a receptacle 35 formed in the bell manifold 30 mounted on an exterior surface of the bell applicator 1.

5 The injector 11 is shown in more detail in Fig. 7 and has a hollow valve body 19 with a seat 20 formed at an upper end of a central stem 21 to function as a valve. The valve is opened by supplying air pressure to a lower surface of a pilot piston 22 attached to a lower end of the stem 21. A spring 23 abuts an upper surface of the piston 22 to close the valve when the air pressure is removed. Radially extending supply port 24 and return
10 port 25 allow unused paint to re-circulate in the supply lines 6. A face or radial seal 26 on the exterior surface of the body 19 mates with the wall of the bell applicator paint receptacle 35. A piloting surface 27 formed on the upper end of the valve body 19 engages with a corresponding surface (not shown) of the paint receptacle 35 to align mating components during the docking process. A small burst of solvent and air can be
15 directed from the bell applicator 1 to clean exposed surfaces of the receptacle 35 and the injector 11 as they disengage upon completion of the fill cycle.

As shown in Fig. 6, the fluid control valve 8 is mounted inside a section 29 of the robot arm A and is connected by a flexible fluid line 46 to the bell manifold 30 mounted on the bell applicator 1. The valve 8 controls the flow of cleaning fluids to the manifold
20 30 and can electrically isolate charged fluid on an output side connected a fluid supply line 31 and an input side connected to a dump line 47. The manifold 30 includes pilot operated valves 32, 33 and 34 (Fig. 5) connected between a common point and the paint receptacle 35, an inlet port 36, and an outlet port 37 respectively. A first short passage 38 (Fig. 6) connects the outlet port 37 with a fluid side of a canister 39 that contains a
25 piston 40 and a drive means 41 for the piston. A second short passage 42 connects the fluid side of the canister 39 to a bell cup 43 of the bell applicator 1. A trigger valve 44 controls the flow of fluid through the passage 42 from the canister 39 to the bell cup 43. The shroud 9 surrounds the bell cup 43 and houses shaping air components (not shown). The bell applicator 1 can be docked to one of the paint supply lines 6 controlled by a
30 pilot operated injector valve 48.

As shown in Fig. 8, the fluid control valve 8 has a moving portion 49, a stationary portion 50, and a linear actuation means 51 for reciprocating the portion 49 relative to the

portion 50. The moving portion 49 includes a supply stem valve 52 and a dump stem valve 53 that feed into a common axial surface surrounded by a face seal 54. The stationary portion 50 has a stem valve 55 that can block the flow of cleaning fluids out to the bell applicator 1 and allow the mating face of the two ports 49 and 50 to be cleaned prior to disengaging the fluid control valve 8. An air gap is created between the facing surfaces of the portions 49 and 50 when the valve is disengaged. This air gap insulates the cleaning fluid supply and dump lines from high voltage that is applied to the bell applicator 1 when paint is dispensed. Each of the stem valves 52, 53 and 55 is air-actuated and spring closed. As a design option, a paint stem valve (not shown) can be added to the moving portion 50 for purposes of supplying paint. The paint stem valve would feed into the common axial surface shared by the other stem valves.

Fig. 9 is a table showing the states of various components of the voltage block and color change apparatus according to the present invention during the clean and fill operation that incorporates the following steps:

- 15 a) Painting is completed with green paint.
- b) The internal paint supply components and the bell cup are cleaned and the desired paint injector is indexed into position all while the robot is enroute to the filling station. A small amount of cleaning fluid is flushed out the bell cup while the piston is agitated up/down near the end of its stroke.
- 20 c) The bell applicator docks with the red paint supply line (the paint receptacle engages with red paint injector).
- d) A small amount of red paint is fed to the bell cup with the piston bottomed out.
- e) The canister fills with red paint.
- 25 f) As the bell applicator releases from the docking station, a small amount of cleaning fluid is ported from the bell applicator to clean the paint receptacle and the injector.
- g) The face of the fluid control valve is cleaned and disengaged (block voltage).
- h) The robot paints with red paint.

Fig. 10 shows the painting robot **R** with the bell applicator **1** mounted on the robot wrist **2** attached at an end of the arm **A** as depicted in Fig. 1. However, a filling station **3'** is shown mounted in an alternate location on the carriage **5** of the robot. The

filling station 3' includes the plurality of paint injectors 11 for selectively coupling with the manifold 30 on the bell applicator 1 for filling the paint canister 39 as described above.

A fourth alternate embodiment filling station 3d is shown in Fig. 11. The injectors 11 extend upwardly from an upper surface of a tubular manifold 60 surrounding the shroud washer 7. The manifold 60 is mounted on a base 61 for up and down movement as indicated by a double-headed arrow 62. In an extended position as shown in Fig. 11, the selected injector 11 couples with the bell manifold 30 for filling the canister 39. In a retracted position shown in dashed line, the injectors 11 are somewhat protected against overspray and physical damage from collisions with the robot arm. In this embodiment, the bell applicator 1 positions the manifold 30 over the selected one of the injectors 11.

There is shown in Fig. 12 a prior art bell applicator 65 mounted on a wrist 66 of a robot arm 67. The applicator 65 houses an electric servomotor 68 driving a ball screw 69 that pushes a piston 70 of a paint canister 71. The prior art bell applicator 65 has several shortcomings. The electric servomotor 68 and attached cabling 72 are potential ignition sources within the hazardous environment of a paint booth. Provisions must be made to isolate the motor 68 and the cabling 72 from the hazardous environment. Explosion proof motors are costly due to a sealed and pressurized enclosure 73 that is required. It is difficult to provide a safe and reliable routing for the electric cable bundle 72 that must flex with the wrist articulation. The cable that passes through the confined space of the hollow wrist 66 is subjected to complex bending and torsion. Cable construction that is approved for hazardous environment is not safe for use under these flexing conditions. Placing the cable 72 inside a pressurized nylon tube 74 (Fig. 12A) increases its overall diameter and stiffness making it difficult to route through the hollow wrist 66.

It is desirable to minimize the mass and package size of equipment mounted on a robot wrist to reduce the required load capacity of the robot arms and drives and to avoid interference with the work piece and the environment. The prior art electric servomotor 68 packaged at the wrist 66 adds payload to the robot and consumes valuable interior space. The apparatus according to the present invention overcomes these shortcomings.

As shown in Fig. 13, an electric servomotor 80 is located in a robot arm 81 such that it is not part of and does not move with a bell applicator 82 that is attached to a robot

The motor **80** can be positioned inside an existing pressurized enclosure **89** that houses other motors used to drive the robot axes. Using a common enclosure reduces cost. Alternatively, the motor **80** can be located outside the paint booth. Breakage of the grounded flexible rotary shaft **84** is not considered a potential ignition source within the hazardous paint booth environment. Eliminating the motor **80** from the paint applicator assembly reduces the mass and size of the wrist mounted applicator **82** resulting in reduced cost and avoiding electrical cables flexing through the wrist **83**.

Another embodiment of the bell applicator according to the present invention is shown in Figs. 14 and 15 wherein the motor is mounted in an enclosure in the bell applicator and motor wires are placed within sealed and air pressurized nylon tubing as they flex through the robot wrist. A miniaturized purge system with control hardware is placed inside the motor enclosure. An electric servomotor **90** is mounted inside a sealed enclosure **91** on a bell applicator **92** and drives a ball screw assembly **93** that pushes on a piston **94** in a canister **95** to dispense paint to a rotating bell cup **96**. Electric wires **97** connected to the motor **90** are routed inside nylon tubes **98** that flex through a robot wrist **99** along with other service lines that comprise an applicator bundle **100**. One end of each of the nylon tubes **98** is in fluidic connection with the motor enclosure **91**. The other end of each of the tubes **98** is in fluidic connection with an enclosed portion **101** of a robot arm structure **102**. The tubes **98** and the enclosures **91** and **101** are fed pressurized air from an air supply **103** that connects to the arm structure **102**. This arrangement keeps the motor **90**, the wires **97** and associated connections separated from the hazardous spray booth environment.

A purge pressure switch **104** and a maintenance pressure switch **105** are mounted inside the motor enclosure **91** to sense pressure relative to atmosphere. A purge pressure relief valve **106** is mounted in the motor enclosure **91** and a safety pressure relief valve

107 is mounted in the enclosed portion 101. The purge pressure relief valve 106 cracks open to allow a predetermined amount of fresh air from the air supply 103 to purge the sealed environment. The purge pressure switch 104 confirms internal pressure is above the cracking pressure of the purge relief valve 106. The maintenance pressure switch 105
5 detects a nominal internal pressure required to prevent the hazardous spray booth environment from entering the sealed environment. The safety relief valve 107 cracks to protect the sealed environment from an overpressure condition.

A clamp 108 rigidly clamps the bundle 100 to the bell applicator 92 near the robot wrist 99. The clamp 108 is designed to cluster the bundle lines around a common
10 axis to minimize the motion and strain on the lines. The clamp 108 isolates the connection end of the bundle lines at the applicator 92 from the loads generated as the bundle 100 flexes through the wrist joint 99. Insulation displacing connectors 109 are used at the arm end of the wires 97 routed inside the nylon tubes 98. This allows for quick replacement of the flexing wires 97.

15 The voltage block and color change apparatus according to the present invention includes an improved filling or docking station and operating sequence as shown in Figs. 16-18. The apparatus includes such improvements as: a shortened on-arm cleaning circuit that can be quickly dried to provide voltage block; a dual "V-shape" injector stack that reduces docking station size; a single solenoid actuated air pilot valve that controls
20 all paint injector valves; and a fail safe design to protect against inadvertently opening an injector.

As shown in Fig. 16, the bell applicator 92 includes a cleaning fluid dump line 111 that is routed directly into a filling or docking station 112 instead of back through the robot arm 102. This shortens the length of line exposed to high voltage during painting.
25 Tests indicate that a remaining fluid supply line 113 can be dried in an acceptably short time period to achieve sufficient voltage isolation from the grounded robot arm structure 102.

The bell applicator and docking station fluid circuits shown in Fig. 16 include a plurality of valves 114A through 114L. A single solenoid actuated air pilot valve 114K
30 in the docking station 112 is used to actuate a row of paint injector valves with only two such valves 114F and 114G being shown. Air pilot pressure is ported through the valve 114K to the selected injector from a common supply manifold 115 that docks to the rear

of an injector manifold 116. The pilot pressure opens the selected injector valve 114F. The sequence of operation is as follows:

1. A firing cylinder 117 pushes the supply manifold 115 to engage with the injector manifold 116.
 2. The firing cylinder 117 continues to extend until the injector manifold 116 engages with the bell applicator 92.
 3. The remotely located air pilot valve 114K opens to provide pilot pressure to the injector valve 114F.
 4. The injector valve 114F opens and paint is fed into the bell applicator 92.
- The operation of the valves 114A through 114L is set forth in a table of Fig. 17 for a paint color change. The operation of the valves 114A through 114L is set forth in a table of Fig. 18 for refilling the canister 95 with the same color paint.

Fig. 19 is a perspective view of the bell applicator 92 in a docking position at the docking station 112. The station 112 is formed by two vertical rows, a left row 118 and a right row 119, of stacked injector manifolds 116 in a V-shaped configuration on a support frame. Each of the injectors 116 has an interface surface 120 and an interface axis 121 perpendicular thereto. The two rows 118 and 119 of the paint injectors 116 are oriented such that each injector 116 in one row lies in a common horizontal plane with a corresponding injector 116 of the other row. The interface axes 121 of the two injectors 116 in a common plane intersect a vertical shroud cleaner axis 122 at a common point 123. This arrangement allows the bell applicator 92 to be centered in the shroud cleaner (not shown) while docked with either row 118 and 119 of the paint injectors 116. If, for example, the bell applicator 92 is to be docked with the uppermost injector 116 in the right row 119, the right row is positioned to align the interface axis 121 with the point 123 as shown in Fig. 19. The bell applicator 92 has a docking surface and paint receptacle 124 that is oriented towards the right row 119 into alignment with the interface axis 121. The firing cylinder 117 associated with the right bank 119 is actuated to push the uppermost paint injector 116 towards the surface/receptacle 124. This design arrangement reduces the height of the docking station 112 by a factor of two (two rows of injectors versus one row per Fig. 4) while retaining a common shroud cleaner.

As shown in Fig. 20, each of the injector manifolds 116 is mounted on a linear slide 125. The injector manifold 116 is pneumatically pushed towards the bell applicator

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.